Fourth Quarterly Report

for

CHARACTERIZATION OF NICKEL-CADMIUM ELECTRODES

1 April, 1964 - 1 July, 1964

Contract No. NAS 5-3477

Prepared by

General Electric Company

Advanced Technology Laboratories

Schenectady, New York

for

Goddard Space Flight Center

Greenbelt, Maryland

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SUMMARY

The objective of this contract is to develop a method of analysis and characterization of the electrodes used in nickel-cadmium sealed cells. It is based primarily on a comparison of detailed polarization measurements of single electrodes before and after periodic operation in selected modes of cyclic testing of cells at three temperature levels 0^{o}, 25^{o} and 40^{o}C. A correlation of this data should provide a basis for specifying improved cells for space applications as well as comparing cells from various manufacturers.

During this quarter, cell cyclic tests except for the Random Discharge Tests (RA), were in progress. The Shallow Discharge Cycling Tests (CC) were interrupted temporarily for specimen examination by x-ray, photomicrography, electrochemical capacity determination, re-characterization, etc. The Random Discharge Test equipment program was changed as a result of the substitution of double pole double throw relays for the stepping relays originally specified. In addition to being more reliable in the event of certain types of failure, the new program also allows for a somewhat greater number of events per unit time. The Constant Voltage, Current Limited Charging Cycling Tests (RB) continue. Examination of these and the Random Discharge plates will proceed in the next quarter.

An improved apparatus for determining the gassing characteristics of positive electrodes was constructed and additional data was collected on four positive plates at four charging rates at room temperature.

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1.0 INTRODUCTION

This report covers the work done during the fourth quarter of an 18 month program to develop a method for the analysis and characterization of the electrodes used in nickel-cadmium spacecraft batteries.

The goal of the program is to develop a correlation between detailed characterization data obtained on single electrodes and the behavior of these electrodes in cells in various modes of cyclic operation. Such a correlation will provide a basis for specifying improved cells for space application and comparing cells from various manufacturers.

A breakdown of the program into tasks is given in Table 1. The test program is divided into two parts: one, the initial characterization testing of plates (Task IV); and the other, the cycling of cells made from characterized plates in selected modes of operation (Tasks V - VII). Periodically, test cells will be removed from tests and the individual electrodes will be recharacterized and examined for changes in physical properties and comparisons made to the original characterization data.

The initial characterization will be made by analysis of data taken in single electrode experiments based on the use of continuous recording of charge-discharge curves under various testing regimes. The characterization information will include: 1) polarization of each electrode under various conditions, 2) complete charge and discharge curves showing electrode capacity, impurity levels, onset of gassing, graphitic and antipolar capacity, and reproducibility of cell operation, and 3) the onset of changes in capacity under various operating conditions.

All plates in the program will be SAFT type VO, prepared as for space cells. Tests will be made at three temperatures: 0^{o}, 25^{o}, and $40^{o}C$. Failure analysis on cycled cells will be made, using visual, mechanical, chemical and electrochemical procedures.

During this quarter, work was completed on the characterization of electrodes, the fabrication of test cells, and the insertion of these cells into the various cyclic tests. Test cells are cycling in two of the three types of cyclic tests to be performed and the disassembly and examination of the shallow discharge test cells has been started.

The blistering of the positive test electrodes (Saft VO) as previously reported, occurs during the overcharge portion of the charging reaction. These have been compared electrochemically with parallel extended overcharge tests

with a group of positive plates from the Battery Product Section (KO-15). The latter suffered no pimple or blister formation even after as much as 675% overcharge in 31% KOH. By comparison, some VO plates formed pimples with as little as 110% overcharge in 31% KOH. Both types of plates are made by the some process but in two different plants. The substrate and active material loading is the same although the KO-15 plates were somewhat larger than the VO positive plates.

80 KO-15 plates have been trimmed to the same dimensions (1.75" x 3.00") as the VO plates, electrochemically cleared and characterized. These will be used as replacement electrodes in the various cycling tests during the next quarter.

TABLE I

PROGRAM TASKS

NAS 5-3477

	TASK		MEASUREMENTS
I.	Control and Recording Equipment Design and fabrication of test equipment.		None
II.	Test Cell Assemblies Design and fabrication of test cells.		None
III.	Electrode Preparation Electrochemical cleaning of reference and cell electrodes, inspection and welding of identification tabs.		Capacity check and weight.
IV.	Characterization Test - CA and CB	C-A	Determine charge curve.
	C-A Constant current charging at C/10, C/5 and C .		Determine rate of gassing from electrodes. Determine rate of O_2 recombination.
	C-B Constant current discharging at C/10, C/5 and C.	C-B	Determine discharge curve.
V.	Shallow Discharge Cycling Tests C-C.	C-C	Make periodic capacity determination.
	Constant current cycling to 25-35% range to determine memory effects.		Make analysis of physical properties. Recovery test.
VI.	Random Discharge Tests R-A.	R-A	Periodic charge and discharge curve.
	Random discharges averaging 10%, 25%, 50% and 75% depth of discharge over a 6-day period using Gaussian and rectangular distribution for discharge periods.		Recharacterization tests.
VII.	Constant Voltage, Current Limited Charging Cycling Tests R-B.	R-B	Periodic charge and discharge curve.
	Charge at C/5 rate and discharge at C/2 rate to 0.9 volts.		Recharacterization tests.

2.0 DISCUSSION

The work accomplished during this quarter included the completion of the initial characterization of electrodes, the continuation of gas rate studies on nickel electrodes, the assembly of cyclic test cells and putting these cells on cyclic tests (Tasks V - VII) as outlined in Table I. In addition, the shallow cycling (CC) tests have been interrupted and the test cells disassembled preparatory to the various physical, chemical, etc. measurements to be made. The details of the work accomplished are reported in the following sections.

2.1 Test Cell Assemblies - Task II

An improved test cell and apparatus was constructed to measure the rate of gas evolution from positive electrodes as a function of charging rates. These tests are part of the initial characterization tests of Task IV.

The basic change in the new system is the use of a small calibrated gas collecting volume which is vented to the environment at a preset pressure differential. This system makes it more convenient to run experiments for longer periods of time and at higher gassing rates than the apparatus described in the last quarter.

The Schematic Diagram of the new apparatus is shown in Figure 1.

The Lucite test cell has three compartments and contains six electrodes in the following arrangement:

Compartment I	Positive reference electrode	R_1
	Negative cadmium counter electrode	C_1
Compartment II	Nickel screen auxiliary electrode	A_2
	Positive test electrode	T_2
Compartment III	Nickel screen auxiliary electrode	A_3
	Negative cadmium counter electrode	C_3

The compartments are separated from each other by baffled walls and the electrodes are completely submerged in an excess of 31% by weight potassium hydroxide electrolyte. The cell is covered by a lid which was screwed to the cell container. The gas tight seal between lid and container consists of a neoprene gasket. A gas outlet tube, located at the center of the lid, leads to the gas measuring device.

The two auxiliary electrodes A_2 and A_3 respectively, are omitted in this drawing.

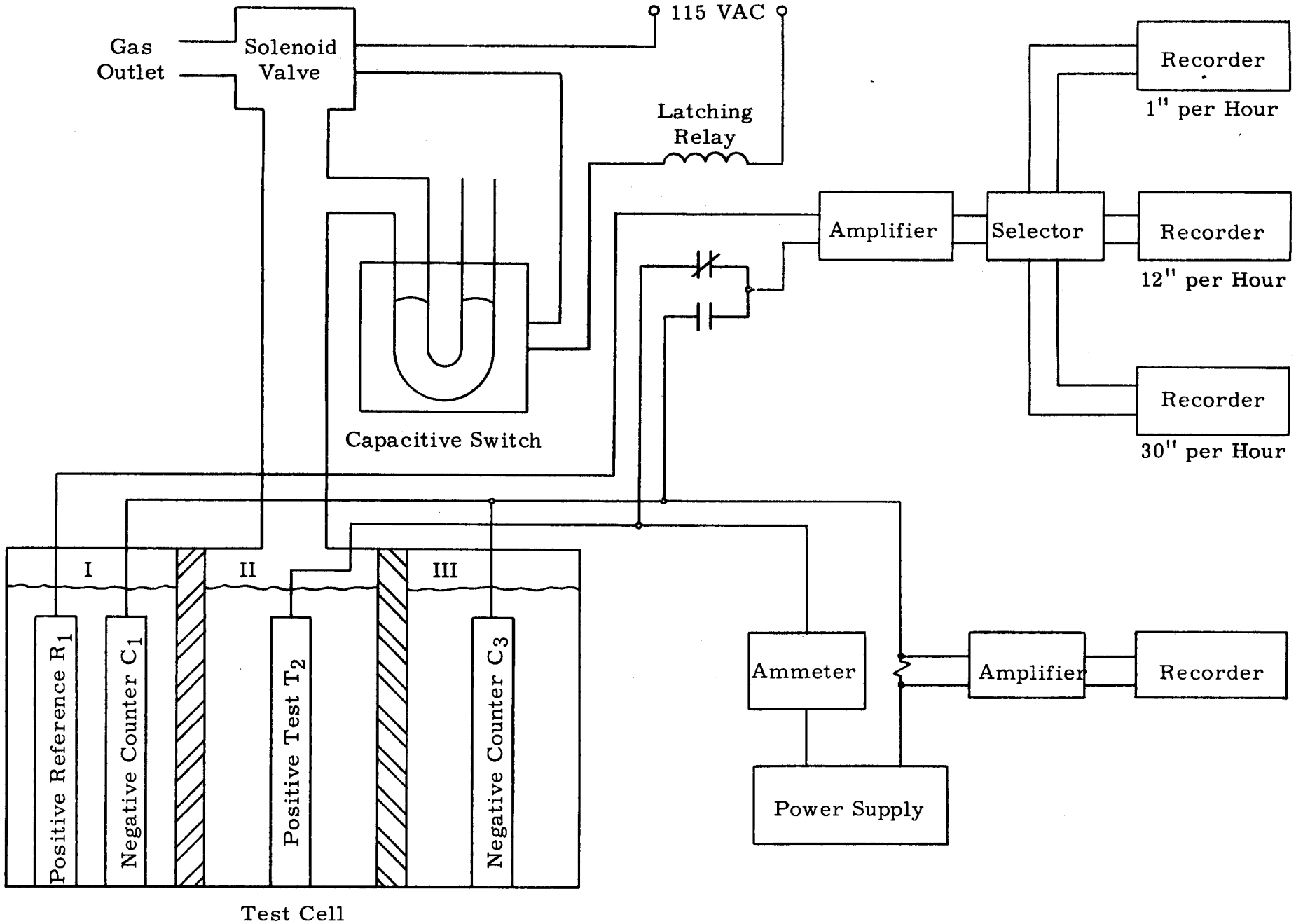

Figure 1. Present Gas Evolution Measuring Apparatus.

In operation, as gas is evolved from the test electrode, the pressure within the closed system begins to rise until the pressure reaches a pre-set value at which the capacitive switch is activated. Then in turn the normally closed solenoid valve is opened, the accumulated gas escapes, the pressure in the system returns to its initial value and the solenoid valve is closed again.

Each activation of the valve releases a constant volume of gas and concurrently changes the polarity of the latching relay. The potentials of the test electrode vs. the reference electrode or the negative counter electrodes vs. the reference electrode are alternately fed into the amplifier. By means of the selector switch, a recorder with an appropriate speed of paper transport can be connected to the amplifier.

After the first release of gas, the resulting recorder charts show two distinctive broken lines, representing the potential vs. time curves of the test electrode and the counter electrodes, respectively.

For evaluating these charts, either the distance between two subseqent events is measured or the number of events per unit of time are counted. As each event represents a constant amount of gas evolved and released, the gassing rate in milliliter per unit of time can easily be calculated.

The system was calibrated before starting runs with each new electrode. This procedure is as follows: A constant direct current was passed between the auxiliary electrode A_2 and the two counters C_1 and C_3 so that oxygen was evolved from A_2. The currents applied represented charge rates of C/10, C/5, C/2 and 1C, respectively, based on the known capacities of the test electrodes.

After a full gassing of the auxiliary electrode was accomplished, the times elapsed between two subsequent activations of the solenoid valve were measured by means of an electric stop watch and an average value for Δt was calculated for each current using between 20 and 30 individual measurements each.

The volume, V_r, released per activation is the product of two constants, namely, V_o = the total volume of the system and,

f = the pre-set, dimensionless activation pressure of the capacitive switch.

and it can be calculated from,

$$V_r = V_o \times f = \text{const.} = n_{th} \times \Delta t$$

where n_{th} = theoretical gas evolution rate in ml sec^{-1}

Δt = the average length of time between two subsequent activations.

The reproducibility of V_r for the currents used was good, and a numerical value of about one milliliter was observed for different experimental set-ups.

2.2 CA-CB Test - Task IV

Three-hundred-forty Saft VO plates have been characterized (170 positives and 170 negatives). The majority of these have been characterized at a nominal C/10 rate at room temperature. The cycle conditions for the C/10 rate tests were, charge for 720 minutes at 0.140 amp and discharge for 600 minutes at 0.160 amp. In addition, 80 KO-15 plates from the Battery Product Section* have been trimmed to 1.75" x 3.00" (test program plate size), weighed, identified and electrochemically cleaned and characterized at the C/10 rate. These plates were found to be less prone to pimpling and blistering and will be used as substitute plates for electrodes removed from the cycling tests in the next quarter.

Correlation of variation of capacity during the CA-CB cycling is continuing as time permits. The data will be available as needed for comparison with the recharacterized electrodes.

2.2.1 Oxygen Evolution - As part of the initial characterization data, the start of oxygen evolution and the rate of oxygen evolution as a function of charging rate will be determined for a limited number of positive electrodes. The data will provide a reference point for comparison with similar measurements which will be made on plates periodically removed from the cyclic tests. During this quarter, measurements were made on four positive plates at four charging rates C/10, C/5, C/2 and C. All runs were made at room temperature.

2.2.1.1 Procedure - Each experimental run at a given charge current started with a checking of the constancy of V_r by means of evolving oxygen from A_2 and measuring the times between subsequent activations of the solenoid valve. No deviations of V_r from the previously established values were detected.

Immediately after this test calibration, the test electrode T_2 was charged against the two counters C_1 and C_2 respectively, while the onset of oxygen gassing from T_2 and the increase of the gassing rate were recorded on one of the event recorders mentioned above.

Regardless of the charge rate applied, a total of 2,000 mAhrs per run was passed through the cell before the test electrode was put on rest. The rest period varied from 10 minutes to two hours, depending on the timing of the program.

The test electrode then was discharged against the cadmium counters at the C/2 rate, and the capacity discharged C_d was calculated from the breaking point of the potential vs. time curve of the test electrode.

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* General Electric Co. Plant at Gainesville, Florida

As soon as the potential of the test electrode reached the region of hydrogen evolution, the discharge of T_2 was terminated. The discharge of the counter electrodes was then continued against the auxiliary A_2 in order to prepare the counter electrodes for the following experiment.

2.2.1.2 Results - Four Saft VO plates were tested. Two of these electrodes P7-3 and P7-4 had several large blisters and the other two P0-70 and P1-42 contained only small pimples. As previously reported, these develop during the overcharge portion of the charging cycle. The selection was made with a view to determining if the blistered electrodes exhibited different gassing behavior than those with pimples only.

The data points for each run are listed in Appendix I. The Y value is the percentage of input energy being converted into gas. The X value is a normalized state of charge factor.

$$X = \frac{C_t - C_g}{C_d} (100)$$

where C_t = total amp-hr. input to the cell up to time t.

C_g = total amp-hr. consumed in oxygen evolution up to time t.

C_d = amp-hr. capacity of test plate determined by discharge measurement to break point in potential-time discharge curve.

The results for electrode P7-3 are shown in Figure 2. Results for the other electrodes are similar. Analysis of the results shows no correlation between the charge rates and the relative position of the corresponding curves for the electrodes tested to date.

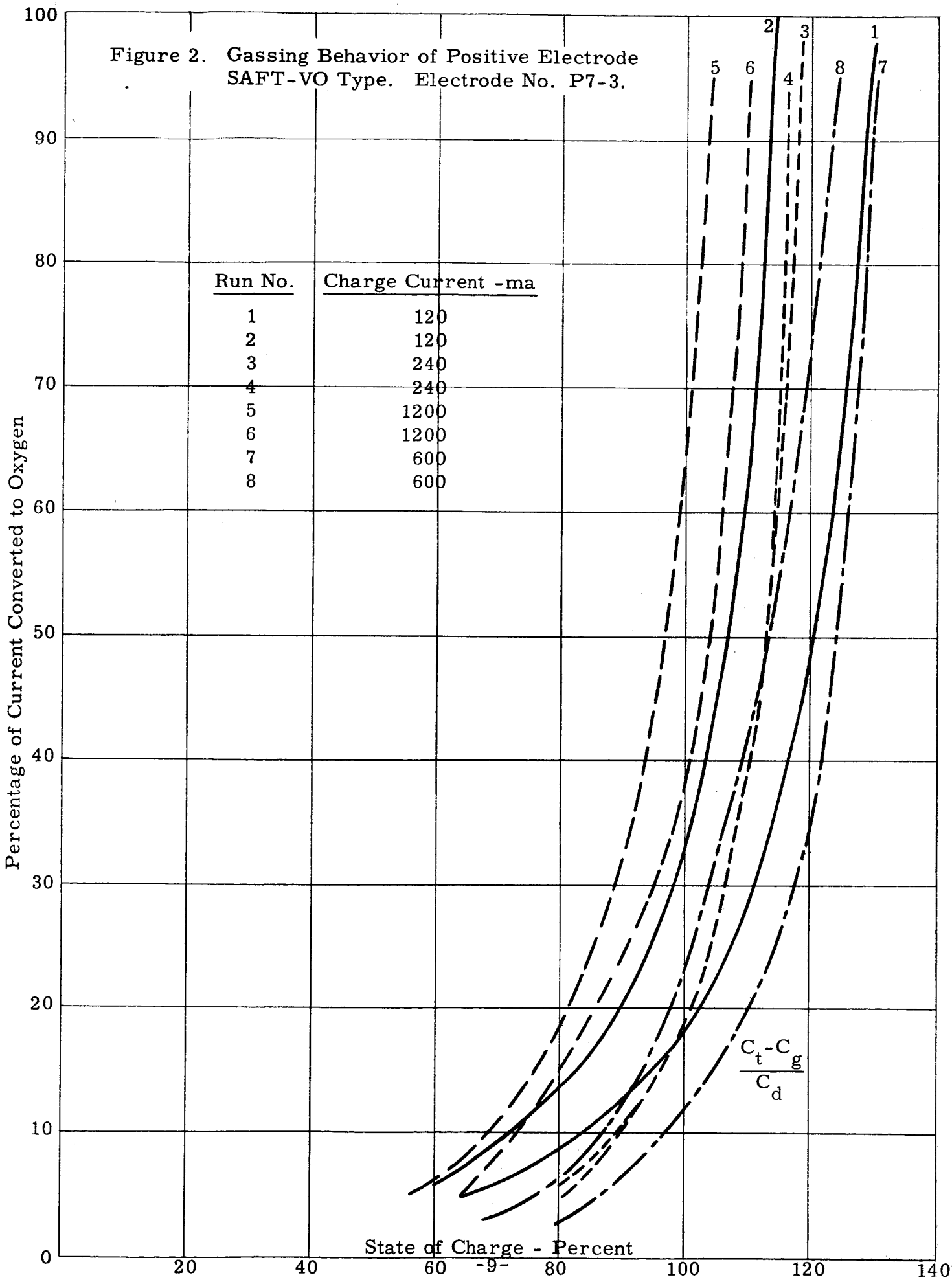
Furthermore, when an average curve for each of the four electrodes was calculated from these data and these four curves were plotted in a similar diagram, no correlation between the physical state of the electrodes and the relative positions of the curves could be detected.

The maximum spread of the data for all tests along with the average for all runs, is shown in Figure 3.

As can be seen from Figure 3, the evolution of oxygen from the positive test electrodes is measurable on the average when the electrode has accepted 50% of its full state of charge.

With increasing state of charge, the portion of the charge current used for oxygen evolution increases non-linearly and on the average, at a state of charge of 100 per cent, about 40 per cent of the charge current goes into oxygen gassing. In almost all cases, a state of charge of 120 per cent results in a total conversion of the charge current into oxygen evolution.

Figure 2. Gassing Behavior of Positive Electrode SAFT-VO Type. Electrode No. P7-3.



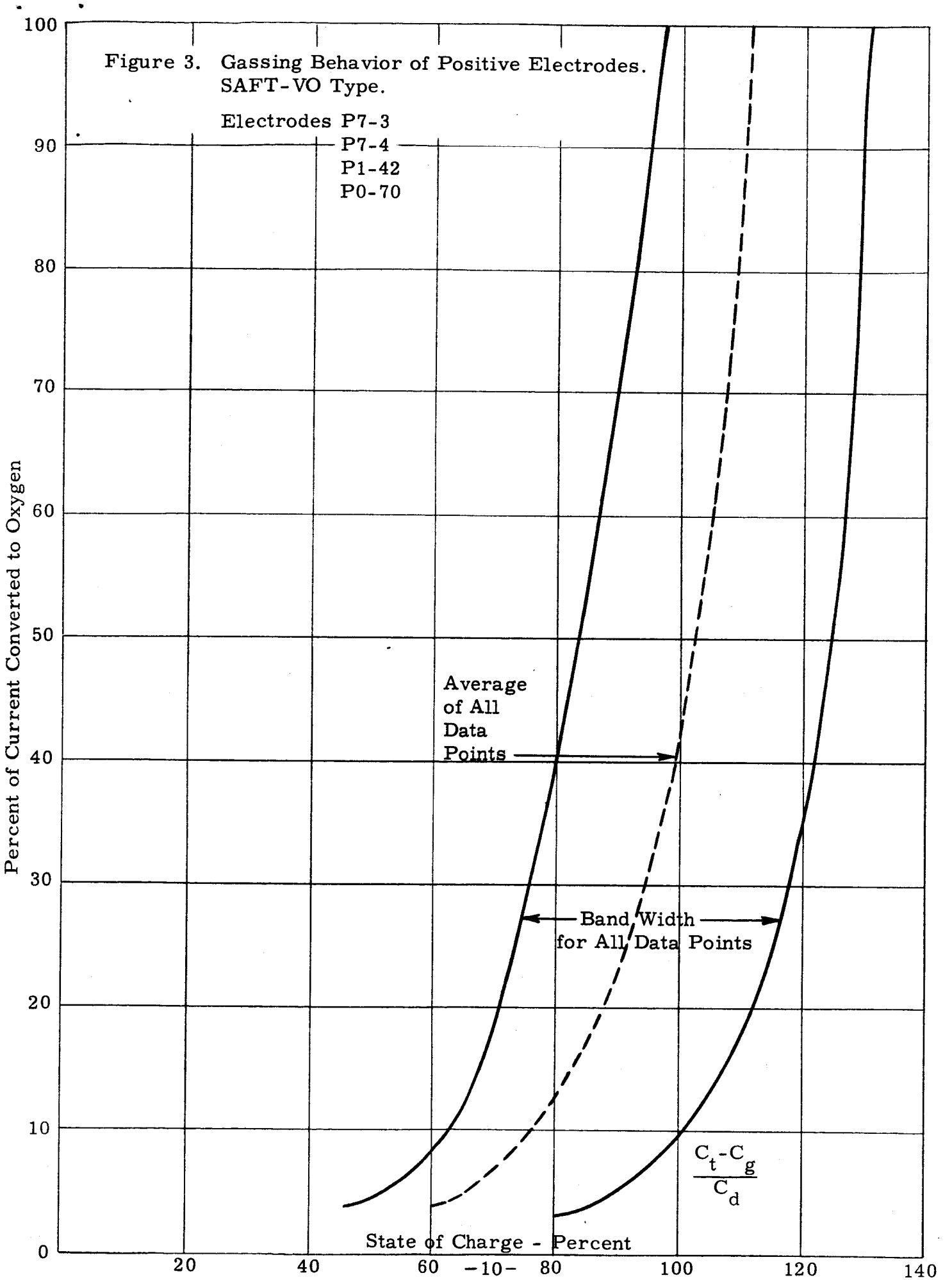


Figure 3. Gassing Behavior of Positive Electrodes. SAFT-VO Type.
Electrodes P7-3
P7-4
P1-42
P0-70
Percent of Current Converted to Oxygen
100
90
80
70
60
50
40
30
20
10
0
Average of All Data Points
Band Width for All Data Points
$\frac{C_t - C_g}{C_d}$
State of Charge - Percent
20
40
60
-10-
80
100
120
140

2.3 Shallow Discharge Cycling C-C Tests - Task V

The nine test cells in this group have been cycled on a 25% depth of discharge cycle at three temperature levels (0°, 25° and 40°C). The cycle conditions are discharged for 35 minutes at 1.7 amperes and charged for 55 minutes at 1.3 amperes.

All of the test cells have been removed from the charge-discharge cycling preparatory to electrode examination and testing. The electrodes involved are described in Table II. All were examined visually and found to be in fair condition generally with few to many pimples on the positive plates. Some had many blistered areas while the active material actually spalled off others in the process of removal from the test cells.

The felted nylon separator material suffered some degradation in that some of the fibers adhered to the electrodes and tore the separator on pulling the electrode and separator apart. There seemed to be no correlation between the 0° and 25°C test conditions and degree of degradation. The extent of this type of degradation was greater in two of the 40°C test cells in spite of course of the shorter testing time involved. In these cases, the separator was badly torn on disassembly. In two cells (CC #'s 1 and 6), the separator was burned through in the short circuit areas. The separator material showed little or no signs of degradation in the other cells.

It is planned for the next quarter to examine by x-ray diffraction and photomicrography a nickel and cadmium electrode from each cell. One each of the electrodes will be tested for residual capacity. These latter plus the unused electrodes will be returned for further cycling.

Some preliminary work has been done using x-ray diffraction equipment to determine the applicability of the tool to plaque examination. In principle, it should be possible to determine qualitatively the nature of materials present at various depths in the various electrodes. This will be accomplished by examining the top layer and two different depths in the interior of the plaque by successive steps.

Experiments are now being performed to find a satisfactory method of "potting" the electrodes (assumed to have a residual charge) for both x-ray and photomicrography. Photomicrography seems to present no problems for the positive plates since charged nickel electrodes hold their charge well in the dry state. The resin should, however, present a minimum of x-ray scattering with no peaks in the regions of interest to us. The problem appears to be more complex in the case of the cadmium plates since they lose approximately 30%

TABLE II

CC TEST CELL ELECTRODES AFTER INTERRUPTION OF TEST CYCLES

CC # (# cycles)	Charact'n Condition	Test Temp.	Cadmium Electrodes	Nickel Electrodes	Comment	Electrode Condition
5 (2579)	C/1	25°C	N_1 - 41, 42, 43, 44, 45	P_1 - 43, 45, 46, 49		P - No visible change. N - No visible change.
3 (2660)	C/10	25°C	N_1 - 21, 22, 23, 24, 25	P_1 - 21, 22, 23, 24		P - All are pimpled, P_1-23 has large blister. N - No visible change.
1 (2660)	C/5	25°C	N_1 - 1, 2, 3, 4, 5	P_1 - 1, 2, 3, 4,	Test cell found to be shorted out - No obvious reason.	P - Pimpled-two short circuits. N - No visible defects except for 2 short circuits.
4 (2078)	C/10	0°C	N_1 - 26, 27, 28, 29, 30	P_1 - 25, 26, 27, 28		P - All extensively pimpled, active mat'l spalling off. N - No visible defects except for black scum on surface.
6 (2078)	C/5	0°C	N_1 - 51, 52, 53, 54, 55	P_1 - 53, 54, 57, 61	Test cell found to be shorted out.	Cell not disassembled - external appearance is good except for short circuit areas.
7 (849)	C/10	40°C	N_1 - 46, 47, 48, 49, 50	P_1 - 90, 91, 92, 94		P - No visible change. N - No visible change.
9 (849)	C/3	40°C	N_1 - 71, 72, 73, 74, 75	P_1 - 73, 74, 75, 77		P - Blisters & pimples, some spalling off of active material. N - Good with some black scum; separator tore extensively on disassembly.
2 (849)	C/5	40°C	N_1 - 6, 7, 8, 9, 10	P_1 - 5, 6, 7, 8		P - Badly blistered, much loose black material. N - Good with black scum; separator adheres to electrodes.

of their residual available charge on drying. Available is a key word since it appears from other work that the capacity is not truly "lost" if the drying is done in the absence of oxygen.

Typically the cadmium test electrodes are found to have a capacity of 1200 - 1400 mAhrs. The capacity is determined by charging the electrode at 460 ma (approx. C/2) until gassing occurs followed by discharge to 0.6 volts at 460 ma and then to 0.1 volt through a constant load of 10 ohms. When rinsed in distilled water, acetone and dried in the abssence of air, the electrodes are found to have a capacity of about 800 - 1000 mAhrs (approx. 30% decrease). A subsequent recharge to gassing (less than the total experimental capacity is required) returns the electrode to its previously measured capacity. The interpretation made is that the drying step does not actually reduce the capacity but rather temporarily blocks a portion of it.

Table III shows the calculated depth of penetration of the x-ray beams of different wave lengths. The depth of the active material is of the order of 0.4 mm in the test plaques and the deepest penetration of the Molybdenum radiation is less than 0.1 mm at the specific angles of interest to us. The presence of the potting material will reduce the depth of penetration slightly.

2.4 R-A Tests - Task VI

These tests are designed to determine the effect of cell operation in which the average depth of discharge for all cycles over a period of a week is fixed at pre-determined levels of 10, 25, 50 and 75%. At each level, the depth of discharge for a given cycle is selected on a random basis. Two types of distribution for the depth of discharge of individual cycles over the period of a week are to be used: one based on a Beta distribution and the other a rectangular distribution.

All RA test cells are now ready to be cycled according to the proposed Random number program. Because of persistant problems with the original stepping-relay control, a somewhat less flexible (no rest periods may be used) but more reliable double pole double throw relay system has been substituted in the control machinery. The new program tape runs for 6 days, 18 hours and includes 20 - 30% more intervals per tape cycle. This is shown in Table IV.

TABLE III

DEPTH OF EFFECTIVE PENETRATION OF INCIDENT RADIATION ON NICKEL PLAQUES*

Angle $2\theta^{o}$	compound	(mm x 10^{-3}) Depth of penetration for various X-ray sources Mo K α	Co K α	Zn K α
8.4^{o}	β -NiOOH	14.5	9.0	2.5
8.9^{o}	$Ni(OH)_2$	16.0	10.0	2.5
15.2^{o}	$Ni(OH)_2$	28.5	19.0	4.3
17.6^{o}	$Ni(OH)_2$	33.0	21.5	5.0
29.4^{o}	β -NiOOH	54.0	36.0	8.3

* The depth of penetration of the incident beam on the cadmium plaques would be somewhat deeper with Mo Kα and somewhat shallower with Co Kα and Zn Kα radiation.

TABLE IV

RA REVISED TAPE PROGRAM COMPARISONS

	10% β	25% β	25% Rect.	50% Rect.	50% β	75% β Dis
#Event-Cycles Original	67	29	29	15	15	11
Av. Depth Dis. Original	9.76%	26.2%	25.6%	51.3%	50.7%	75.4%
#Event-Cycles Revised	95	36	34	19	19	13
Av. Depth Dis. Revised	9.8%	25.9%	26.7%	49.3%	51.2%	71.5%

The test cells for the RA test have been assembled and are ready for testing. The revised program tape is being prepared and should be ready for use early in the next quarter. Table V is a tabulation of the test cell electrodes showing their intended test conditions.

TABLE V

RA TEST - POSITION SUMMARY

Timer #	1	2	3	4	5	6
% Av. Dis.	10% β	25% Rect.	25% β	50% Rect.	50% β	75% β
Room Temp.	N-5 N-6 P-1	N_3-5 N_3-6 P_1-30	N_3-3 N_3-4 P_1-29	N-3 N-4 P_1-98	N_0-58 N_0-59 P_3-15	N_3-9 N_3-10 P_1-99
40°C	N_3-11 N_3-15 P_3-9	N_0-61 N_0-63 P_0-68	N_0-67 N_0-68 P_0-71	N-7 N-8 P-8	N-1 N-2 P_1-95	N_1-98 N_0-60 P-3
0°C	N_0-69 N_0-70 P_1-67	N_0-64 N_0-66 P_1-69	N_3-16 N_3-17 P_3-13	N-9 N-11 P-9	N_3-21 N_3-22 P_3-24	N_3-18 N_3-19 P_3-23

2.5 RB Tests - Task VII

All RB tests are underway. A total of 238 cycles have been completed on the room temperature cells and 46 on the others by the end of this quarter. These tests are designed to determine the effect of cyclic operation under constant voltage, current limited charging conditions. Charge voltages are 1.50, 1.47 and 1.42 v respectively at 0^{o}, 25^{o} and 40^{o} centigrade with the current limited at 0.80A for 7 3/4 hours. This is followed by discharge at 2.0A to 0.9 volts followed by a rest period for a total of 10 3/4 hours per cycle.

The electrodes involved in this test are shown below in Table VI.

TABLE VI

RB TEST SUMMARY

RB Cell#	Temp.	Electrodes	Cycles Completed
1	25^{o}C	P_5 - 2, 4, 7, 11 N_5 - 3, 4, 6, 9, 10	238
2	25^{o}C	P_0 - 79, 85, 93, 96 N_1 - 81, 83, 85, 96, 97	228
3	0^{o}C	P_0 - 64, 67, 78; P_1 - 79 N_0 - 53, 54, 55, 56, 57	46
4	0^{o}C	P_5 - 18, 24, 27, 28 N_5 - 15, 16, 17, 18, 20	46
5	40^{o}C	P_5 - 3, 14, 15, 17 N_5 - 10, 11, 12, 14, 15	46
6	40^{o}C	P_5 - 23, 29; P_1 - 35; P_0 - 63 N_5 - 2, 5, 7, 8; N_0 - 51	46

3.0 PROGRAM FOR NEXT QUARTER

The measurements on the evolution of oxygen from positive electrodes will continue, using KO-15 positives and selected electrodes removed from the cyclic tests.

The examination, capacity determinations, and recharacterization of electrodes from the cyclic tests will be continued.

4.0 NEW TECHNOLOGY REPORT

There were no new developments during this quarter which come under the "New Technology" clause of this contract.

APPENDIX I

ACTUAL COORDINATES OF EXPERIMENTAL CURVES FOR OXYGEN EVOLUTION

Electrode P7-3

Run	Rate	X	Y	Run	Rate	X	Y
1	C/10	64	5	2	C/10	60	6
		80	9			70	9
		90	13			80	14
		100	18			90	21
		110	30			100	33
		120	49			110	66
		124	66			112	80
		128	85			114	100
		130	98				
3	C/5	80	5	4	C/5	80	6
		90	10			90	10
		100	18			100	18
		110	43			110	40
		114	66			114	60
		116	80			116	94
		118	98				
5	1 C	56	5	6	1 C	64	5
		68	10			80	15
		80	18			90	25
		90	33			100	37
		100	65			104	48
		102	84			108	70
		103	95			109	84
						110	85
7	C/2	79	3	8	C/2	68	3
		90	7			80	6
		100	12			90	12
		110	19			100	24
		120	34			110	44
		124	48			120	76
		128	68			124	95
		129	95				

APPENDIX I

(continued)

Electrode P7-4

Run	Rate	X	Y	Run	Rate	X	Y
1	C/5	82	10	2	C/5	72	5
		90	13			84	14
		100	26			90	19
		104	44			100	40
		108	95			104	55
						108	73
						110	92
3	1 C	72	8	4	C/10	94	16
		80	17			98	21
		90	22			100	26
		100	44			104	34
		104	55			106	42
		108	75				
		110	94				

APPENDIX I

(continued)

Electrode P1-42

Run	Rate	X	Y	Run	Rate	X	Y
1	C/10	72	5	2	C/10	64	5
		80	9			76	10
		90	18			90	24
		94	30			100	52
		100	52			104	74
		104	74			106	96
		107	98				
3	C/2	58	5	4	C/2	62	5
		64	10			70	11
		72	22			76	20
		80	40			80	30
		88	64			84	40
		92	78			90	60
		96	94			96	80
						100	96
5	1 C	46	4	6	1 C	80	4
		60	8			90	6
		70	13			100	11
		80	22			110	18
		90	34			120	28
		100	56			126	40
		104	76			132	48
		106	91			136	82
						137	95
7	C/5	63	5	8	C/5	62	6
		80	11			80	10
		90	20			90	17
		100	37			100	29
		104	48			104	36
		108	64			108	58
		112	95			112	67
						114	94

APPENDIX I

(continued)

Electrode P0-70

Run	Rate	X	Y	Run	Rate	X	Y
1	C/10	53	4	2	1 C	62	4
		74	8			80	14
		80	12			90	27
		90	18			100	56
		100	26			102	70
		110	40			104	87
		120	62				
		124	75				
		128	90				
3	C/5	67	4	4	1 C	67	4
		84	11			80	10
		94	21			90	20
		100	32			100	43
		104	42			104	64
		108	61			106	87
		110	87				
5	C/5	71	4	6	C/2	66	4
		84	10			78	10
		100	29			90	22
		104	40			98	38
		108	58			104	59
		110	81			106	73
						109	96
7	C/2	74	4	8	C/10	67	6
		88	16			76	10
		98	38			90	24
		102	54			100	44
		104	69			106	60
		106	96			112	88
						114	99